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(54) METHOD AND APPARATUS FOR USING SOFTWARE DEFINED NETWORKING AND NETWORK FUNCTION VIRTUALIZATION TO SECURE RESIDENTIAL NETWORKS

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H04L 12/28 (2006.01)

(52) **U.S. Cl.**
CPC ***H04L 63/0272*** (2013.01); ***H04L 12/2803*** (2013.01); ***H04L 63/0281*** (2013.01); ***H04L 63/101*** (2013.01)

(58) **Field of Classification Search**
CPC H04L 63/101; H04L 12/2803; H04L 63/0272; H04L 63/0281; H04L 63/029; H04L 63/00; H04L 63/02–63/0218; H04L 63/10; H04L 63/14; H04L 63/1441–63/1483; H04L 63/20–63/205; H04L 63/08
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

8,693,374 B1 8/2014 Murphy et al.
2005/0193429 A1* 9/2005 Demopoulos G06F 21/552 726/23

(Continued)

OTHER PUBLICATIONS

N. Feamster. Outsourcing home network security. In Proceedings of the 2010 ACM SIGCOMM Workshop on Home Networks, HomeNets '10, pp. 37-42, New York, NY, USA, 2010. ACM.

(Continued)

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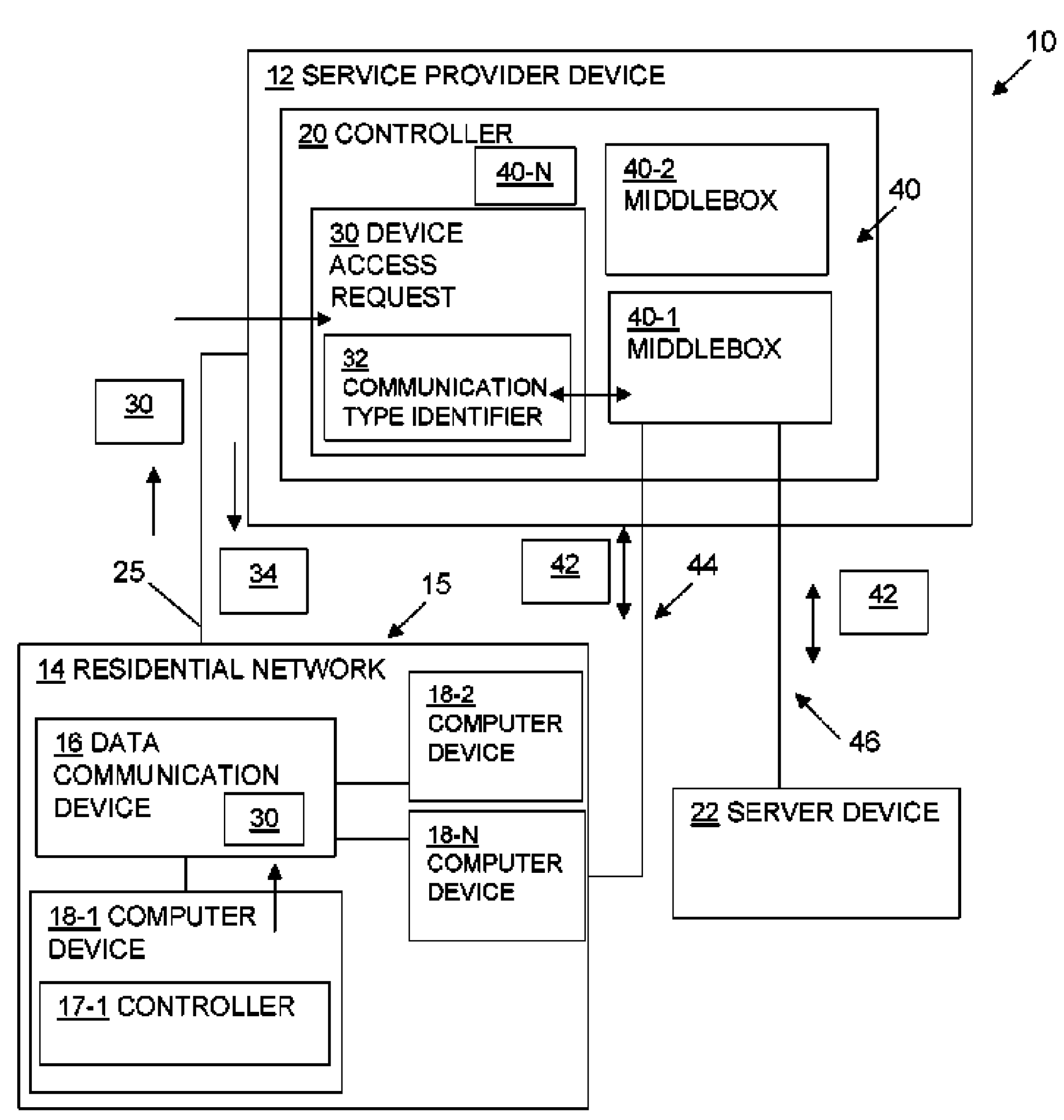
(57) **ABSTRACT**

A service provider device includes a controller having a memory and a processor. The controller is configured to receive a device access request from the client device via a residential network, the server provider device being located external to the residential network and detect a communication type identifier associated with the device access request. The controller is configured to establish a secure communication channel between the client device and a middlebox associated with the detected communication type identifier and provide communication between the client device and the server device via the secure communication channel between the client device.

18 Claims, 5 Drawing Sheets



(56) **References Cited**

U.S. PATENT DOCUMENTS

2012/0167185	A1*	6/2012	Menezes	H04L 9/3213 726/5
2013/0276082	A1*	10/2013	Kuang	H04L 63/0869 726/7
2014/0355436	A1	12/2014	Zhang et al.	
2016/0301779	A1*	10/2016	Cui	H04L 45/566
2016/0373414	A1*	12/2016	MacCarthaigh	H04L 63/0435

OTHER PUBLICATIONS

G. Gibb, H. Zeng, and N. McKeown. Outsourcing network functionality. In Proceedings of the First Workshop on Hot Topics in Software Defined Networks, pp. 73-78, 2012.
A. Matos, S. Sargento, and R. L. Aguiar. Waypoint routing: Anetwork layer privacy framework. In Global Telecommunica-tions Conference (GLOBECOM 2011), 2011 IEEE, Dec. 2011.
S. Mehdi, J. Khalid, and S. Khayam. Revisiting traffic anomaly detection using software defined networking. In R. Sommer, D. Balzarotti, and G. Maier, editors, Recent Advances in Intrusion Detection, vol. 6961 of Lecture Notes in Computer Science, pp. 161-180. Springer Berlin Heidelberg, 2011.
R. Mortier, T. Rodden, P. Tolmie, T. Lodge, R. Spencer, A. crabtree, J. Sventek, and A. Koliousis. Homework: Putting interaction into the infrastructure. In ACM Symposium on User Interface Software and Technology, pp. 197-206, 2012.
J. Sherry, S. Hasan, C. Scott, A. Krishnamurthy, S. Ratnasamy, and V. Sekar. Making middleboxes someone else's problem: Network processing as a cloud service. In Proceedings of the ACM SIGCOMM 2012 Conference on Applications, Technologies, Architectures, and Protocols for Computer Communication, SIGCOMM '12, pp. 13-24, New York, NY, USA, 2012. ACM.
S. Sundaresan, S. Burnett, N. Feamster, and W. De Donato. Bismark: A testbed for deploying measurements and applications in broadband access networks. In Proceedings of the 2014 USENIX Conference on USENIX Annual Technical Conference, USENIX ATC'14, pp. 383-394, Berkeley, CA, USA, 2014. USENIX Association.
K. Xu, L. Gu, and F. Wang. Monitoring home network traffic via programmable routers. In Global Communications Conference (GLOBECOM), 2013 IEEE, pp. 605-610, Dec. 2013.
Y. Yiakoumis, S. Katti, T.-Y. Huang, N. McKeown, K.-K. Yap, and R. Johari. Putting home users in charge of their network. In Proceedings of the 2012 ACM Conference on Ubiquitous Computing, UbiComp '12, pp. 1114-1119, New York, NY, USA, 2012. ACM.
Y. Yiakoumis, K.-K. Yap, S. Katti, G. Parulkar, and N. McKeown. Slicing home networks. In Proceedings of the 2Nd ACM SIGCOMM Workshop on Home Networks, HomeNets '11, pp. 1-6, New York, NY, USA, 2011. ACM.
H. Kim and N. Feamster. Improving network management with software defined networking. Communications Magazine, IEEE, 51(2)114-119, 2013.
H. Kumar, H. H. Gharakheili, and V. Sivaraman. User control of quality of experience in home networks using sdn. In Advanced Networks and Telecommuncations Systems (ANTS), 2013 IEEE International Conference on, pp. 1-6. IEEE, 2013.
N. McKeown, T. Anderson, H. Balakrishnan, G. Parulkar, L. Peterson, J. Rexford, S. Shenker, and J. Turner. Openflow: enabling innovation in campus networks. ACM SIGCOMM Computer Communication Review, 38(2):69-74, 2008.
Z. Yuan, C. Du, X. Chen, D. Wang, and Y. Xue. Skytracer: Towards fine-grained identification for skype traffic via sequence signatures. In Computing, Networking and Communications (ICNC), 2014 International Conference on, pp. 1-5. IEEE, 2014.

* cited by examiner

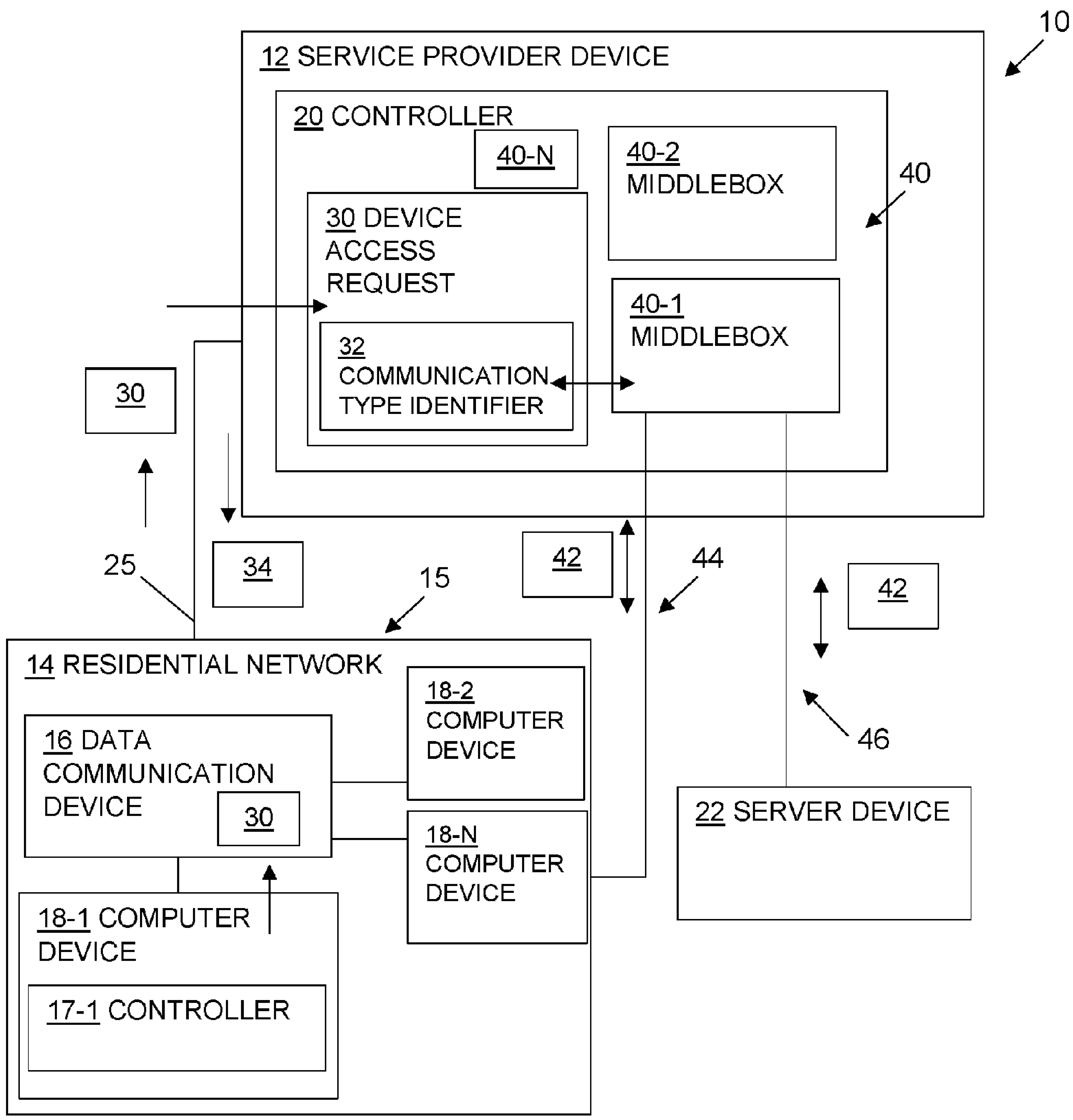

10
12 SERVICE PROVIDER DEVICE
20 CONTROLLER
40-N
40-2
MIDDLEBOX
40
30 DEVICE
ACCESS
REQUEST
40-1
MIDDLEBOX
32
COMMUNICATION
TYPE IDENTIFIER
30
42
44
34
25
15
42
46
14 RESIDENTIAL NETWORK
18-2
COMPUTER
DEVICE
16 DATA
COMMUNICATION
DEVICE
30
18-N
COMPUTER
DEVICE
22 SERVER DEVICE
18-1 COMPUTER
DEVICE
17-1 CONTROLLER

FIG. 1

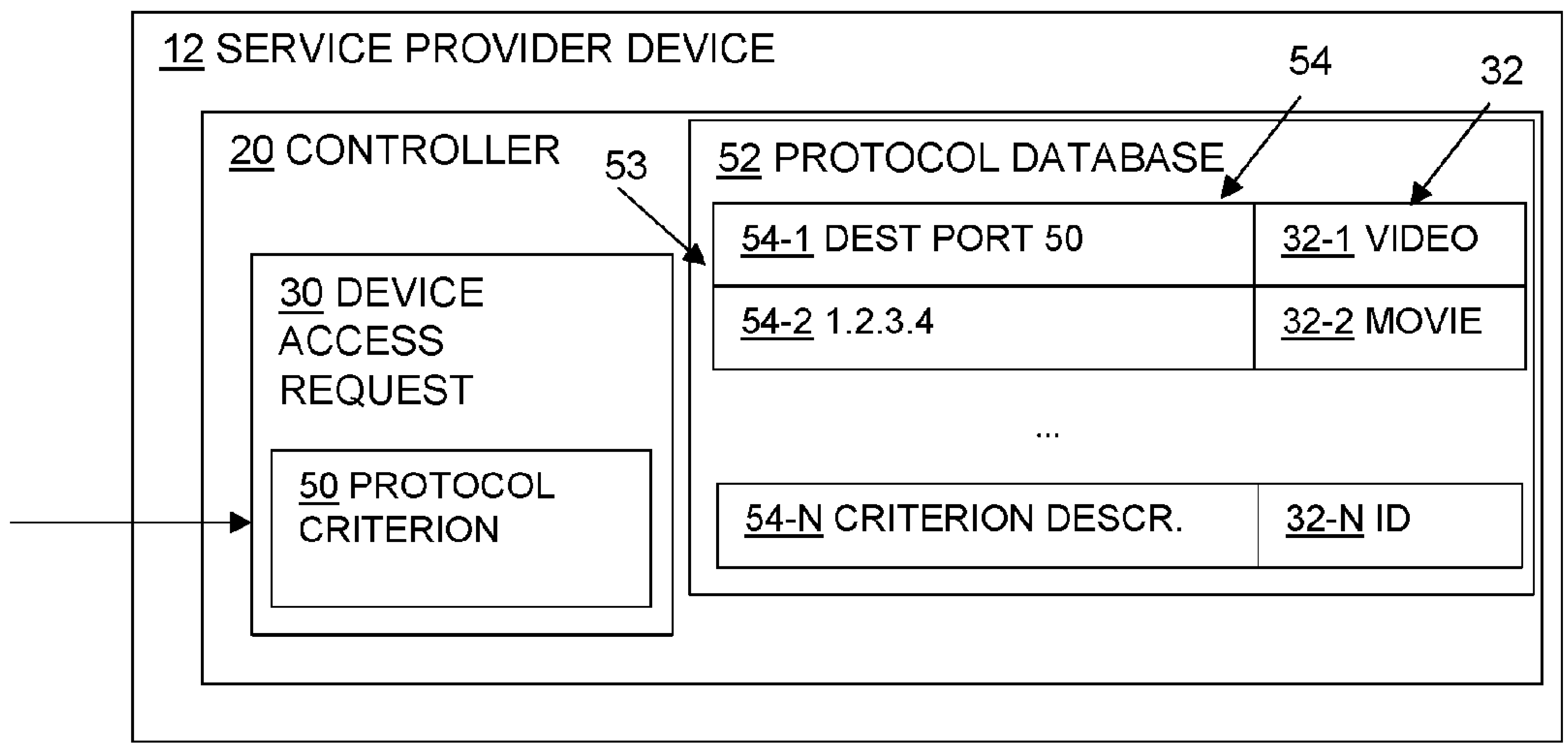

12 SERVICE PROVIDER DEVICE
54
32
20 CONTROLLER
53
52 PROTOCOL DATABASE
54-1 DEST PORT 50
32-1 VIDEO
54-2 1.2.3.4
32-2 MOVIE
30 DEVICE ACCESS REQUEST
...
50 PROTOCOL CRITERION
54-N CRITERION DESCR.
32-N ID

FIG. 2

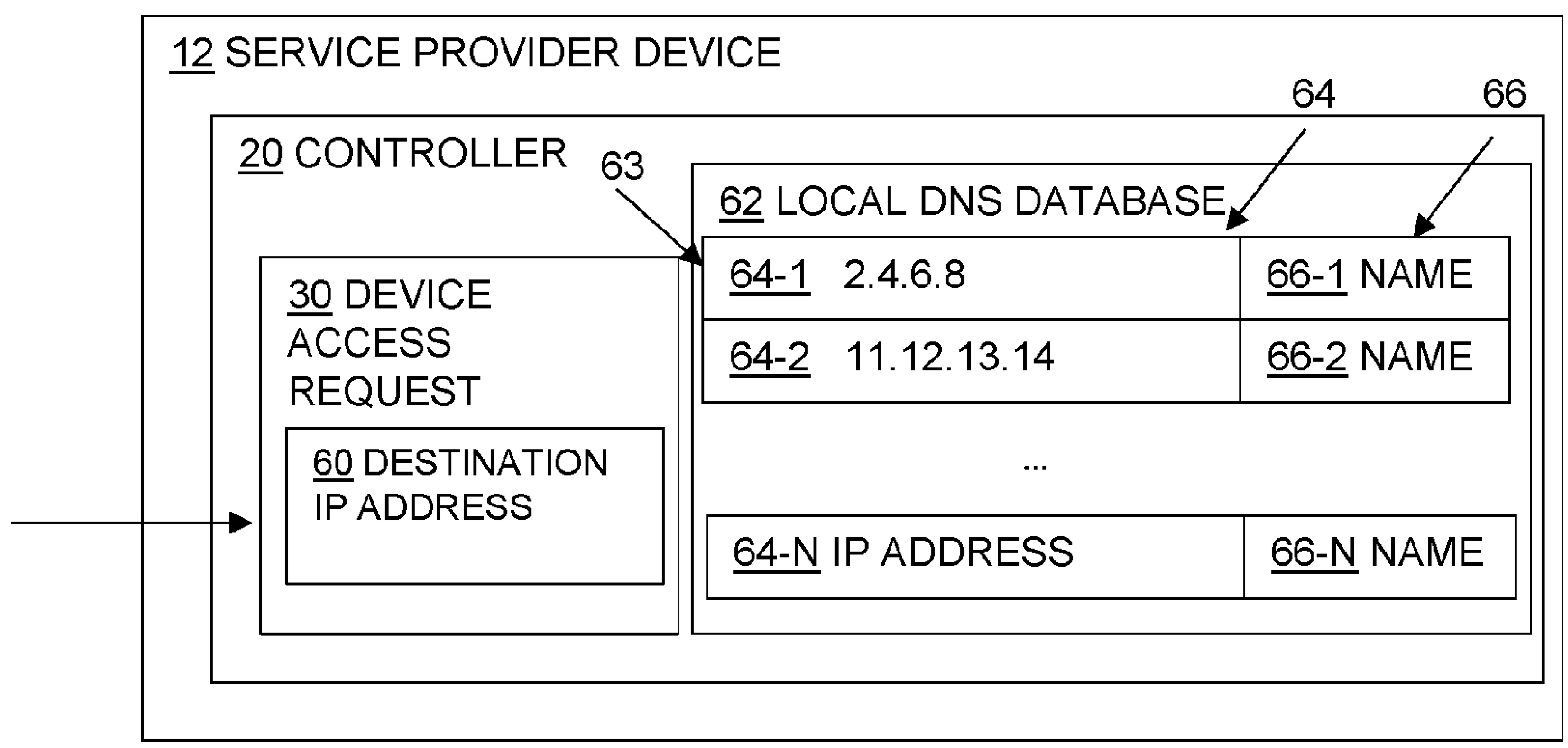

12 SERVICE PROVIDER DEVICE
20 CONTROLLER
63
64
66
62 LOCAL DNS DATABASE
30 DEVICE ACCESS REQUEST
60 DESTINATION IP ADDRESS
64-1 2.4.6.8
66-1 NAME
64-2 11.12.13.14
66-2 NAME
...
64-N IP ADDRESS
66-N NAME

FIG. 3

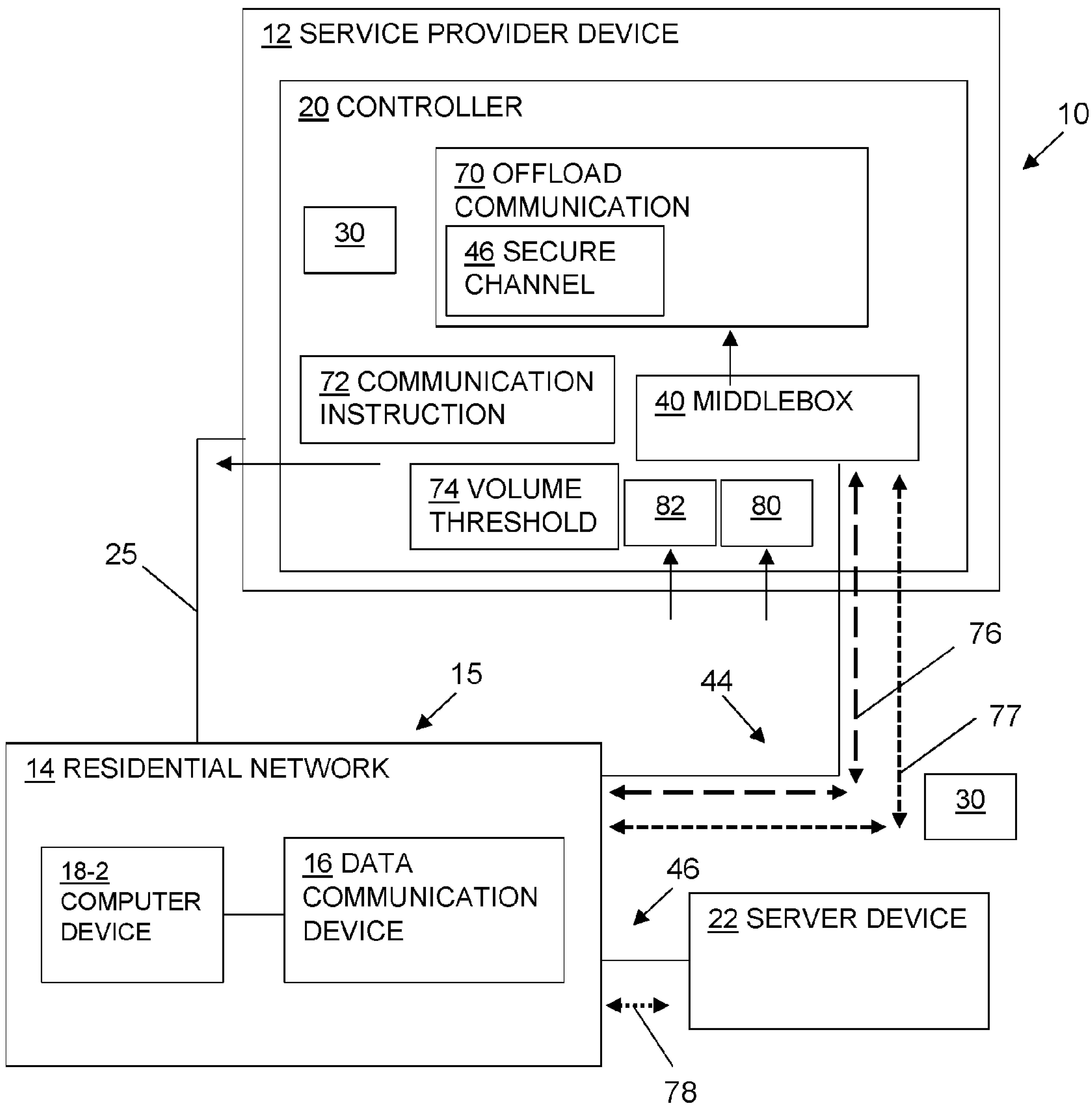

12 SERVICE PROVIDER DEVICE
20 CONTROLLER
10
70 OFFLOAD COMMUNICATION
30
46 SECURE CHANNEL
72 COMMUNICATION INSTRUCTION
40 MIDDLEBOX
74 VOLUME THRESHOLD
82
80
25
76
15
44
77
14 RESIDENTIAL NETWORK
30
46
18-2 COMPUTER DEVICE
16 DATA COMMUNICATION DEVICE
22 SERVER DEVICE
78

FIG. 4

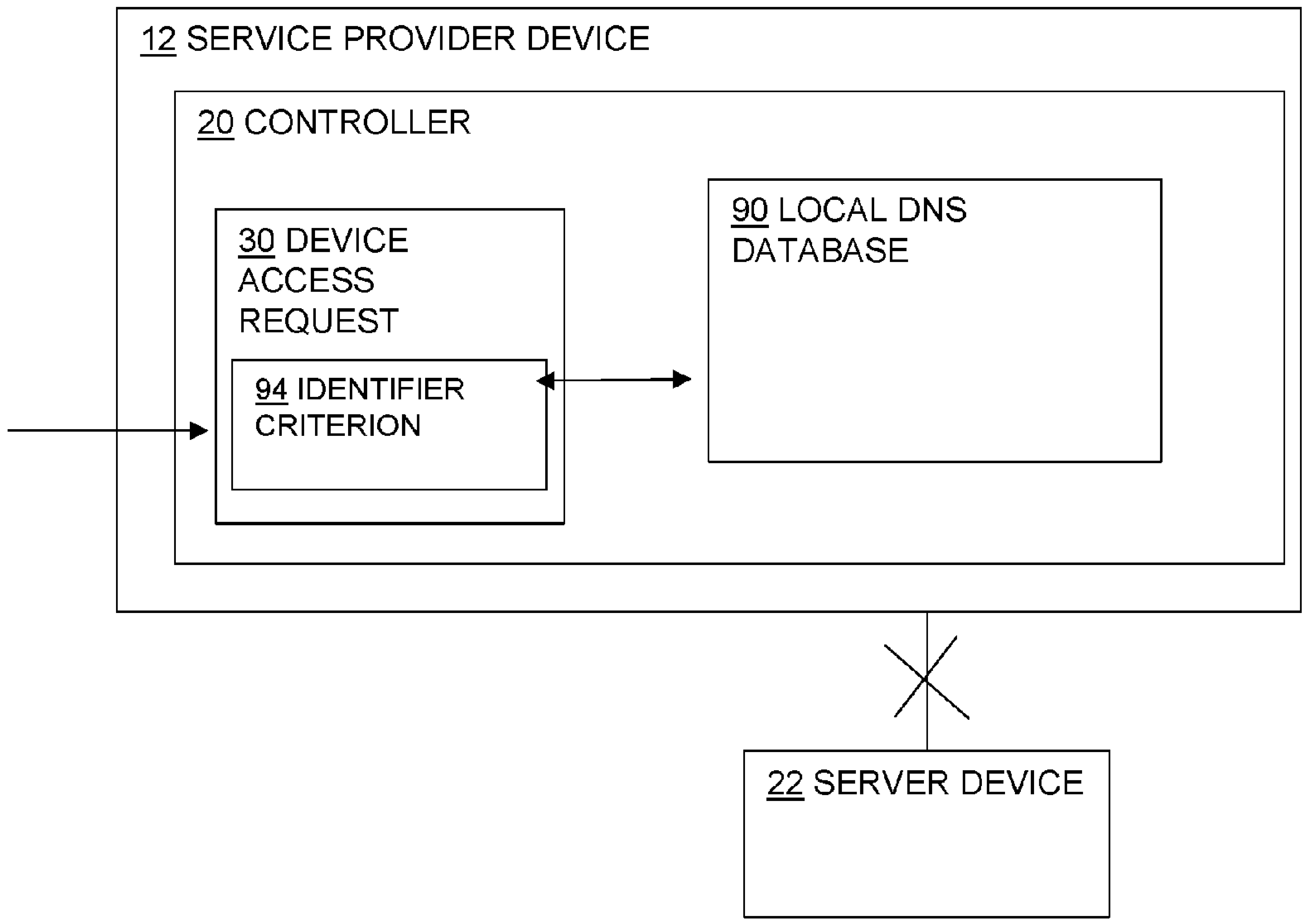

12 SERVICE PROVIDER DEVICE
20 CONTROLLER
30 DEVICE ACCESS REQUEST
94 IDENTIFIER CRITERION
90 LOCAL DNS DATABASE
22 SERVER DEVICE

FIG. 5

METHOD AND APPARATUS FOR USING SOFTWARE DEFINED NETWORKING AND NETWORK FUNCTION VIRTUALIZATION TO SECURE RESIDENTIAL NETWORKS

RELATED APPLICATIONS

This patent application claims the benefit of U.S. Provisional Application No. 62/269,308, filed on Dec. 18, 2015, entitled, "Method and Apparatus for Using Software Defined Networking and Network Function Virtualization to Secure Residential Networks," the contents and teachings of which are hereby incorporated by reference in their entirety.

BACKGROUND

Computer networks allow users to access information stored within, or associated with, the network. A typical computer network can include multiple client computer devices that communicate with each other through a system of data communication devices (e.g., switches and routers) and transmission media (e.g., electrical wiring, fiber-optic cable, and/or wireless connections). In general, a transmitting client device exchanges data with a receiving client device by packaging the data using a standard format or protocol to form one or more data structures (e.g., packets, frames, or cells). The transmitting client device transfers these data structures to the receiving client device through the above-described network of computerized devices and transmission media.

Conventional computer networks, such as local area networks (LANs), can be subject to unwanted intrusion or attacks. For example, computerized devices on a network can be subject to user-level network attacks, such as drive-by-downloads (e.g., computer virus or malware) that can occur without a user's knowledge, such as when the user visits a particular website. Network computer devices can also be subject to other types of user-level network attacks, such as phishing attacks, which can obtain relatively sensitive information, such as passwords and user names, from the network computer devices.

SUMMARY

As provided above, conventional local area networks (LANs) can be subject to unwanted intrusion or attacks. Typically, relatively large enterprises and organizations invest in the security of their LAN networking infrastructures and resources to minimize the likelihood or success of such attacks. For example, organizations can utilize security tools, such as hardware firewalls, proxy servers, and intrusion detection systems, to strengthen their networks and minimize the risk of unwanted intrusion or attacks. These conventional solutions are relatively complex and require relatively larger budgets, and awareness of computer security to properly implement. Further, these organizations typically utilize a dedicated information technology (IT) staff with expertise in networking and security to administer the networks.

Conventional network security mechanisms are directed toward relatively large enterprises and organizations and do not address the needs of relatively smaller LANs, such as residential networks. For example, there are approximately 54 million residential LANs in the United States, which exceeds the number of LANs associated with the approximately 5.8 million U.S. corporations (i.e., enterprises and organizations). The average owner of a residential LAN will

not necessarily have the expertise or budget to utilize network security solutions used by large organizations to limit or prevent network attacks.

Further, while residential-based network security solutions are available, these solutions can be fairly cumbersome to properly implement by the end user. For example, certain network security solutions require residential network owners to administer their networks and to make effective security decisions, despite a lack of training. Residential users often initially configure their networks and then neglect the infrastructure until it fails. This approach can result in residential networks that have relatively weak security which can yield sub-optimal results. Further, these network owners often neglect basic steps related to network security maintenance, such as changing default passwords or installing firmware updates to the security solutions. This provides an opportunity for adversaries to access the residential network. Additionally, residential network owners are at risk for incurring liability for the activity of inside users, such as guests, who use or share the network. For example, guests of a residential network can access illicit content over a connected wide area network without the knowledge of the network owner. In the case where the content is accessed illegally (e.g., an unlicensed download of copyrighted content), the network owner could be held liable for any legal infractions associated with the access.

By contrast to conventional network security solutions, embodiments of the present innovation relate to a method and apparatus for using software defined networking and network function virtualization to secure residential networks. In one arrangement, a service provider network system includes an offsite or cloud-based host, such as a service provider device, which is configured to establish a secure communication channel, such as virtual private network (VPN) connection, between a client device of a residential computer network and a cloud-based proxy device or middlebox. The secure communication channel is tailored to particular applications, workflows, or protocols executed by the computer devices within the residential network on a per-flow basis. That is, the middlebox is configured to monitor and control the network traffic associated with a particular application, workflow, or protocol as executed by the client device.

With such a configuration, the service provider device can secure all traffic exchanges with the residential computer network which allow residential network owners to outsource their network management to a security service provider. This offloads the responsibility of the security of the residential network from the network owner to the security service provider. Further, the service provider device operator can readily deploy new security measures and tools across a large number of residential networks, such as by updating or adding middleboxes to the service provider network system. The service provider device is further configured to direct network communication to a proxy device which, in turn, exchanges communication with targeted server devices over a wide area network, such as the Internet. With such a configuration, the service provider device can hide the network address of the residential network from the server device and other devices on the network, thereby minimizing the risk of the residential network devices as being subject to user-level network attacks.

Embodiments of the innovation relate to, in a service provider device, a method for providing communication between a client device and a server device. The method includes receiving, by the service provider device, a device access request from the client device via a residential network, the server provider device being located external to the residential network. The method includes detecting, by the service provider device, a communication type identifier associated with the device access request. The method includes establishing, by the service provider device, a secure communication channel between the client device and a middlebox associated with the detected communication type identifier. The method includes providing, by the service provider device, communication between the client device and the server device via the secure communication channel between the client device.

Embodiments of the innovation relate to a service provider device including a controller having a memory and a processor. The controller is configured to receive a device access request from the client device via a residential network, the server provider device being located external to the residential network and detect a communication type identifier associated with the device access request. The controller is configured to establish a secure communication channel between the client device and a middlebox associated with the detected communication type identifier and provide communication between the client device and the server device via the secure communication channel between the client device and the middlebox.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and other objects, features and advantages will be apparent from the following description of particular embodiments of the innovation, as illustrated in the accompanying drawings in which like reference characters refer to the same parts throughout the different views. The drawings are not necessarily to scale, emphasis instead being placed upon illustrating the principles of various embodiments of the innovation.

FIG. **1** illustrates a schematic representation of a service provider network system, according to one arrangement.

FIG. **2** illustrates a schematic representation of a service provider device having a protocol database, according to one arrangement.

FIG. **3** illustrates a schematic representation of a service provider device having a local domain name server database, according to one arrangement.

FIG. **4** illustrates a schematic representation of a service provider network system, according to one arrangement.

FIG. **5** illustrates a schematic representation of a service provider device having a whitelist database, according to one arrangement.

DETAILED DESCRIPTION

Embodiments of the present innovation relate to a method and apparatus for using software defined networking and network function virtualization to secure residential networks. In one arrangement, a service provider network system includes an offsite or cloud-based host, such as a service provider device, which is configured to establish a secure communication channel, such as virtual private network (VPN) connection, between a client device of a residential computer network and a cloud-based proxy device or middlebox. The secure communication channel is tailored to particular applications, workflows, or protocols executed by the computer devices within the residential network on a per-flow basis. That is, the middlebox is configured to monitor and control the network traffic associated with a particular application, workflow, or protocol as executed by the client device.

With such a configuration, the service provider device can secure all traffic exchanges with the residential computer network which allow residential network owners to outsource their network management to a security service provider. This offloads the responsibility of the security of the residential network from the network owner to the security service provider. Further, the service provider device operator can readily deploy new security measures and tools across a large number of residential networks, such as by updating or adding middleboxes to the service provider network system. The service provider device is further configured to direct network communication to a proxy device which, in turn, exchanges communication with targeted server devices over a wide area network, such as the Internet. With such a configuration, the service provider device can hide the network address of the residential network from the server device and other devices on the network, thereby minimizing the risk of the residential network devices as being subject to user-level network attacks.

FIG. **1** illustrates a schematic representation of a service provider network system **10**, according to one arrangement. The service provider network system **10** can form part of a wide area network (WAN), such as the Internet, and can include multiple network resources. For example, the service provider network system **10** can include a local area network (LAN), such as a residential network **14** having client devices **15** and a service provider device **12** having associated cloud-based proxy devices or middleboxes **40**.

As illustrated, the residential network **14** can include, as client devices **15**, a data communication device **16**. In one arrangement, the data communication device **16**, such as a computerized device, switch, router, or gateway. The data communication device **16** is configured to exchange network connection communication, such as Transmission Control Protocol/Internet Protocol (TCP/IP) communication, between the residential network **14** and the service provider device **12**. For example, a controller (not shown) of the data communication device **16** can be configured with OpenWrt firmware having an Open vSwitch module enabled to support the OpenFlow protocol. As such, upon boot-up, the data communication device **16** can establish a network connection with the service provider device **12** and can request instruction for all new communication channel requests or network flows, such as requested by the computer devices **18** of the residential network **14**. As a result, during operation, the data communication device **16** is configured to forward network communication from the computer devices **18** of the residential network **14** to a proxy device as directed by the service provider device **12**, rather than to a target server device **22**.

Also as illustrated, the residential network **14** can include, as client devices **15**, one or more computer devices **18-1** through **18**-N disposed in electrical communication with the data communication device **16**. In one arrangement, each one or more of the computer devices **18** can be configured as a laptop, tablet device, or personal computer having a controller **17**, such as a memory and a processor. Alternately, one or more of the computer devices **18** can be configured as a network connected device, such as a printer device photocopy device. Further, one or more of the computer devices **18** can be configured as an embedded device, such as a networked light switch having an associated controller **17**. During operation, the computer devices **18** are configured to exchange network communication with the server device **22** via the data communication device **16** and a proxy device as directed by the service provider device **12**.

The service provider device **12** is a computerized device disposed in electrical communication with a client device **15** of the residential network **14**, such as the data communication device **16**. The service provider device **12** is located external to, or offsite from, the residential network **14**. For example, the service provider device **12** can be configured as part of an offsite, cloud-based service.

In one arrangement, the service provider device **12** is configured to direct the behavior of the data communication device **16** and control distribution of communication between the residential network **14** and a variety of server devices **22** located on the WAN. For example, the service provider device **12** includes a controller **20**, such as a memory and a processor, that executes a connection review protocol, such as an OpenFlow protocol, which is configured to receive and review device access requests **30** (e.g., network connection requests) received from the data communication device **16**.

Also as indicated, the service provider device **12** includes one or more associated middleboxes **40**, such as middleboxes **40-1** through **40**-N. In one arrangement, each middlebox **40** is configured to act as a proxy device for network traffic associated with a particular application, workflow, or protocol executed by the computer devices **18** within the residential network **14** on a per-flow or per-access basis. For example, the first middlebox **40-1** can be configured to proxy and monitor network traffic pertaining to a particular type of video conferencing (e.g., SKYPE) while the second middlebox **40-2** can be configured to proxy and monitor network traffic pertaining to a particular type motion picture streaming (e.g., NETFLIX). With each middlebox **40** being configured to proxy and monitor a particular application, workflow, or protocol, the service provider device **12** can secure any number of applications executed by the client devices **15** across many types of residential networks **14**, regardless of the security concerns or goals.

The middleboxes **40** can be configured in a variety of ways. In one arrangement, each middlebox **40** is configured as a virtual machine executed by the controller **20** of the service provider device **12**, such as illustrated. Alternately, each middlebox **40** is configured as a computerized device disposed in electrical communication with the server provider device **12**.

During operation, the service provider device **12** is configured to establish a secure communication channel, such as a virtual private network (VPN), with a client device **15** of a residential network **14** and to direct communication between the client device **15** and a server device **22**. The following provides a description of an example operation of the service provider device **12** when establishing communication channels and providing such communication.

With continued reference to FIG. **1**, the service provider device **12** is configured to receive a device access request **30** from a client device **15** of a residential network **14**. For example, assume the case where a user of a first computer device **18-1** seeks to establish a video conferencing connection (e.g., SKYPE) with server device **22**. In such a case, the computer device **18-1** generates a device access request **30** identifying the server device **22** and forwards the request within the residential network **14** to the data communication device **16**. While the device access request **30** can be configured in a number of ways, in one arrangement, the device access request **30** is configured as a synchronize (SYN) message as part of a TCP/IP handshake. Upon receipt, based upon the configuration of the data communication device **16** (e.g., as configured with the OpenFlow firmware), the data communication device **16** forwards the device access request **30** to the service provider device **12** via network communication channel **25** (e.g., over a WAN such as the Internet), rather than to the server device **22** identified by the device access request **30**.

In response to receiving the device access request **30**, the service provider device **12** is configured to detect a communication type identifier **32** associated with the device access request **30**. The communication type identifier **32** relates to a particular application, workflow, or protocol to be executed by the computer device **18**. For example, the communication type identifier **32** can indicate a request to access a server device **22** which offers a particular service, such as SKYPE, or motion picture streaming content, such as NETFLIX. By detecting the communication type identifier **32** associated with the device access request **30**, the service provider device **12** can identify the particular application, workflow, or protocol associated with the network traffic from the requesting computer device **18**.

Based upon the detected communication type identifier **32**, the service provider device **12** can select an appropriate, associated middlebox **40** configured to proxy and monitor the application, workflow, or protocol traffic from the client device **15**. For example, assume the service provider device **12** detects the communication type identifier **32** associated with the device access request **30** as pertaining to a particular type of video conferencing (e.g., SKYPE). Based upon such detection, the service provider device **12** can select the first middlebox **40-1**, which is configured to proxy and monitor network traffic pertaining to the particular type of video conferencing (e.g., SKYPE), as the middlebox **40** to proxy and monitor network traffic between the computer device **18**, via the data communication device **16**, and the server device **22**.

Following detection of the communication type identifier **32** associated with the device access request **30**, the service provider device **12** is configured to establish a secure communication channel **44** between the client device **15** and a middlebox **40** associated with the detected communication type identifier **32**. For example, following selection of the first middlebox **40-1** as the network communication proxy, the service provider device **12** is configured to transmit a communication channel instruction **34** to the data communication device **16**, such as by using the OpenFlow protocol. The communication channel instruction **34** can direct the data communication device **16** to establish a secure communication channel **44** between the data communication device **16** and the selected first middlebox **40-1** associated with the communication type identifier **32**. In response to the communication channel instruction **34**, the data communication device **16** can establish dynamically spawned virtual private network (VPN) or a Generic Routing Encapsulation (GRE) tunnel as the secure communication channel **44** with the first middlebox **40-1**.

Next, the service provider device **12** is configured to provide communication **42** between the client device **15** and the server device **22** via the secure communication channel **44** between the client device **15** and the middlebox **40**. For example, based upon the establishment of the secure communication channel **44** with the first middlebox **40-1** the data communication device **16** is configured to transmit network communication **42** to the first middlebox **40-1**. As the first middlebox **40-1** receives the network communication **42** from the data communication device **16** via the secured communication channel **44**, the first middlebox **40-1** performs a network address translation (NAT) on the communication **42** and forwards the communication **42** to the target destination server device **22** via a communication channel **46**. Further as the first middlebox **40-1** receives network communication **42** from the server device **22** via the communication channel **46**, the first middlebox **40-1** performs a NAT on the communication **42** and forwards the communication **42** to the data communication device **16** via secured communication channel **44**.

Accordingly, the service provider device **12** is configured to offload the responsibility of the security of the residential network **14** from the network owner to an offsite security service provider. For example, by establishing a secured communication channel **44** for network communication between a data communications device and a middlebox **40** and by utilizing the middlebox **40** to act as a proxy device relative to a server device **22**, the service provider device **12** can hide the network address of the client devices **15** residential network **14** from the server device **22** and other devices on the wide area network (e.g., Internet). This protects the residential network **14** by hiding the Internet protocol (IP) address of the computer devices **18** on the residential network **14** and minimizes the risk of the residential network devices **15** as being subject to user-level network attacks.

Further, by securing network communication between the client devices **15** of the residential network **14** and the server device **22**, the service provider device **12** allows residential network owners to outsource their network management to a security service provider via an offsite or cloud-based service. This offloads the responsibility of the security of the residential network **14** from the network owner to the security service provider, rather than requiring residential network owners to become experts in network security.

Additionally, the service provider device **12** is located external to, or offsite from, the residential network **14**. For example, the service provider device **12** can be configured as part of an offsite, cloud-based service. With such a configuration, a service provider device operator can deploy updated security measures and security tools across a relatively large number of residential networks **14** in a relatively cost effective manner, without requiring a physical presence in the associated residences. This minimizes the need to the residential network owner to either monitor his own residential network **14** or to utilize relatively costly network security solutions to limit or prevent network attacks.

As indicated above, during operation, the service provider device **12** is configured identify a communication type identifier **32** of a device access request **30**. This allows the service provider device **12** to detect the particular application, workflow, or protocol associated with a network connection originating from the requesting client device **15** before the connection is established. Further, this allows the service provider device **12** to select an appropriate middlebox **40** configured to proxy and monitor the network traffic associated with that application, workflow, or protocol on a per-flow or per-access request basis. The service provider device **12** can be configured to identify the communication type identifier **32** associated with a device access request **30** in a variety of ways.

In one arrangement, with reference to FIG. **2**, when identifying a communication type identifier **32**, the service provider device **12** is configured to first detect a protocol criterion **50** associated with the device access request **30**. The protocol criterion **50** can be configured to identify some aspect of the application, workflow, or protocol associated with a network connection between the client device **15** and the server device **22**. For example, certain network communication associated with a particular application can originate from a particular port, while other network communication associated with a particular protocol can have a particular destination IP address. In such a case, the device access request **30** includes, as the protocol criterion **50**, an originating port number or a destination IP address associated with the device request **30**. When detecting the protocol criterion **50**, the service provider device **12** can extract the protocol criterion **50** from the payload the device access request **30**.

Once the service provider device **12** has detected the protocol configuration **50** associated with the device access request **30**, the service provider device **12** is configured to compare the protocol criterion **50** with a protocol database **52**. In one arrangement, the service provider device **12** can store a preconfigured protocol database **52** which includes entries **53** that relate protocol criterion descriptions **54** to corresponding communication type identifiers **32**. For example, a first protocol description **54-1**, "destination port **50**," corresponds to a first communication type identifier, "video conference service" while a second protocol description **54-2**, IP address "1.2.3.4" corresponds to "motion picture streaming service." Accordingly, in use, the service provider device **12** is configured to compare the protocol criterion **50** with each entry **53** of the protocol database **52** to attempt to identify a particular application, workflow, or protocol associated with the device access request **30** before establishing the network connection.

The service provider device **12** is then configured to detect the communication type identifier **32** associated with the device access request **30** based upon a correspondence of the protocol criterion **50** and an entry **53** in the protocol database **52**. For example, assume the case where the protocol criterion **50** identifies "destination port **50**" as the port of the destination server device **22** with which the data communication device **16** is attempting to establish a connection. Based upon a comparison of the protocol criterion **50** with the entries **53** of the protocol database **52**, the service provider device **12** can identify a correspondence between the protocol criterion **50** and the first protocol description **54-1**. Based upon such a correspondence, the service provider device **12** can identify corresponding communication type identifier **32**, as a video conference service (e.g., SKYPE). By detecting the communication type identifier **32** in this manner, the service provider device **12** can select an appropriate middlebox **40** associated with the video conference service to proxy and monitor the network communication between the data communication device **16** and the server device **22** (i.e., a SKYPE server device).

In the case where the service provider device **12** detects a lack of correspondence between the protocol criterion **50** and the entries **53** of the protocol database **52**, in one arrangement, the service provider device **12** can identify the device access request **30** as indicating a security threat and can drop the device access request **30**. As such, the service provider device **12** will not establish a network connection between the requesting client device **15** and the server device **22**.

In another arrangement, with reference to FIG. **4**, when identifying a communication type identifier **32**, the service provider device **12** is configured to utilize a local domain name server (DNS) database **62**. As illustrated, the service provider device **12** can store the DNS database **62** which includes entries **63** that relate numerical Internet protocol (IP) addresses **64** to corresponding domain or website address names **66**. For example, as provided in the DNS database **62**, a first IP address "2.4.6.8" **64-1** corresponds to a first domain name "www.video-conference.com," **66-1** while a second IP address "11.12.13.14" **66-2** relates to a second domain name "www.movie-stream.com," **66-2**. Accordingly, in use, the service provider device **12** is configured to compare the protocol criterion **50** with each entry **53** of the protocol database **52** to attempt to identify a particular application, workflow, or protocol associated with the device access request **30** before establishing the network connection.

The service provider device **12** is configured to develop the DNS database **62** based upon DNS request resolution performed by client devices **15** of the residential networks **14**. For example, when a client device **15** of the residential network **14** attempts to establish a network connection with a server device **22** via a domain name (e.g., www.name-.com), the computer device **18** forwards a DNS request to a domain name server. In response to the DNS request, the domain name server returns a DNS response, such as a numerical IP address (e.g., 20.21.22.23) corresponding to the domain name, to the computer device **18**. Each time a client devices **15** initiates a DNS request, the data communication **16** is configured, such as via the OpenFlow protocol, to forward a copy of the DNS response to the service provider device **12**. The service provider device **12** then parses the DNS response to identify responses associated with known server device domain names. If the service provider device **12** detects such a response, the service provider device **12** extracts the IP addresses contained within the response and adds each numerical Internet protocol (IP) address **64** and the corresponding domain or website address name **66** to the local DNS database **62**.

In use, and with continued reference to FIG. **3**, when the data communication device **16** transmits the device access request **30** to the service provider device **12**, the device access request **30** includes a destination IP address **60**, such as associated with a particular server device **22** to which the data communication device **16** would like to establish a network connection. In response, the service provider device **12** can extract the destination IP address **60** from the payload the device access request **30**.

The service provider device **12** is configured to then compare the destination IP address **60** with the local DNS database **62**. For example, assume the case where the destination IP address **60** identifies the IP address 11.12.13.14. Based upon a comparison with the entries **63** of the local DNS database **62**, the service provider device **12** can identify the IP address entry "11.12.13.14" **64-2** as corresponding to the destination IP address **60** and can identify the domain name "www.movie-stream.com" **66-2** corresponding to the IP address entry.

The service provider device **12** is configured to then detect the communication type identifier **32** associated with the device access request **60** based upon a correspondence of the destination IP address **60** and an entry **63** in the local DNS database **62**. For example, based upon the correspondence of the destination IP address **60** with the domain name "www.movie-stream.com" **66-2**, as provided above, the service provider device **12** can identify corresponding communication type identifier **32** as a motion picture streaming service (e.g., NETFLIX). By detecting the communication type identifier **32** in this manner, the service provider device **12** can select an appropriate middlebox **40** associated with the motion picture streaming service to proxy and monitor the network communication between the data communication device **16** and the server device **22** (i.e., a NETFLIX server device).

In the case where the service provider device **12** detects a lack of correspondence between the destination IP address **60** and the entries **63** of the local DNS database **62**, in one arrangement, the service provider device **12** can identify the device access request **30** as indicating a security threat and can drop the device access request **30**. As such, the service provider device **12** will not establish a network connection between the requesting client device **15** and the server device **22**.

Returning to FIG. **1**, and as provided above, following the establishment of the secure network connection **44** by the service provider device, the middlebox **40** forms part of the communication path between a client device **15** and a server device **22**. However, in certain cases, the middlebox **40** can introduce relatively large amounts of latency to the communication exchanged between the data communication device **16** and the server device **22**. For certain types of content, such as motion picture streaming or on-line video games, the latency can be unacceptable to the end user. In certain cases, to minimize the effect of the middlebox **40** in the exchange of content between the data communication device **16** and the server device **22**, the middlebox **40** is configured to detect an offload condition associated with the communication between the client device **15** and the server device **22**. In the case where an offload condition is detected, the middlebox **40** is configured to generate and transmit an offload communication **70** to the service provider device **12** to request that the service provider device **12** exclude the middlebox **40** from the communication path between the client device **15** and the server device **22**.

As provided above, the middlebox **40** is configured as a proxy device and is included as part of the network communication exchanged between a client device **15** and a server device **22**. In one arrangement, the middlebox **40** is configured as a monitoring device. While the middlebox **40** can monitor network traffic to maintain the security of the residential network **14**, the middlebox **40** is also configured to detect a state of the connection or network communication exchanged between the client device **15** and the server device **22**. Based on the state of the connection or the network communication (i.e., an offload condition), the middlebox **40** can exclude itself from the communication exchanged between the client device **15** and the server device **22**.

In one arrangement, as part of such a monitoring configuration and with reference to FIG. **4**, the middlebox **40** can detect the establishment of a secure channel, such as an encrypted channel, between the client device **15** and the server device **22** as an offload condition.

For example, certain services or server devices **22** typically provide streaming content, such as video content (e.g., online streaming motion pictures), to subscribing client devices **15** over secure network or communication channels. The communication channels are established by the server devices **22** as secure communication channels in order to minimize illicit interception and/or redirection of the content stream to non-subscribing devices. With the presence of a secure network channel established by the server devices **22**, the use of the middlebox **40** as a monitoring device is not necessary. Accordingly, by detecting the presence of a secure network channel between the server device **22** and client device **15**, the middlebox **40** can remove itself from the communication between the server device **22** and client device **15** while maintaining a level of security associated with the residential network **14**.

For example, during the establishment of the secure communication channel, the device access request **30** provided by the data communication device **16** to the service provider device **12** via network communication channel **25** is configured as a synchronize (SYN) message **30**. This forms part of a handshaking process of a Transport Layer Security (TLS) connection. During operation, when the data communication device **16** transmits such a device access request **30** to the service provider device **12**, the service provider device **12** directs the data communication device to forward the device access request **30** to a selected middlebox **40** (e.g., a middlebox **40** associated with a particular application, workflow, or protocol executed by the computer devices **18**).

In response, the data communication device **16** forwards the request to the middlebox **40** via communication channel **44** (e.g., secure communication channel **44**), such as along path **76**. The middlebox **40** reviews the device access request **30**, can identify the request **30** as a SYN message or packet, and can return the request **30** to the data communication device **16**, such as along path **77**. Upon receipt of the request **30**, the data communication device **16** forwards the SYN packet **30** to the server device **22**, such as along path **78**.

The middlebox **40** is further configured to receive and review acknowledge (ACK) messages transmitted from both the server device **22** to the data communication device **16** and from the data communication device **16** to the server device **22**. For example, in response to the SYN packet **30**, the server device **22** transmits an ACK packet to the data communication device **16**, such as along path **78**. The data communication device **16** receives the ACK packet and transmits the ACK packet to the middlebox **40**, such as along path **77**, for verification. Once returned from the middlebox **40**, the data communication device **16** then generates its own acknowledgement packet, transmits it to the middlebox **40**, and awaits verification from the middlebox **40** before forwarding to the server device **22**. In the case where the middlebox **40** identifies these messages as acknowledgement messages, the middlebox **40** can recognize the communication exchange between the data communication device **16** and the server device **22** as forming a secure communication channel or TLS connection between the middlebox **40** and the server device **22**.

In one arrangement, the middlebox **40** is further configured to validate the TLS connection between the client device **15** and the server device **22** to identify potential security threats to the residential network **14** originating from the server device **22**.

For example, following the handshaking process, as part of the ACK messages transmitted from the data communication device **16** and the server device **22**, the middlebox **40** can receive a Server Hello message from the server device **22** which includes a chain of security certificates **80**. Once received, the middlebox **40** is configured to extract the security certificates **80** from the Server Hello message, including a root certificate. The middlebox **40** can then utilize its own database of trusted root certificates to verify the authenticity of each of the certificates **80** in the chain. In the case where the middlebox **40** detects a failure of the verification process at any point in the chain, the middlebox **40** is configured to break the connection with the server device **22**. In the case where the middlebox **40** detects the certificates **80** as being valid, the middlebox **40** can validate the TLS connection between the client device **15** and the server device **22**. By validating the certificates **80** received as part of the Server Hello message, the middlebox **40** the service provider device **12** can identify potential security threats to the residential network **14** originating from the server device **22**.

In one arrangement, as part of the TLS connection validation, the middlebox **40** is configured to detect revocation of the certificates **80** included with the Server Hello message. For example, for each certificate **80** associated with the Server Hello message identifies an associated certificate revocation list (CRL). During operation, the middlebox **40** is configured to iteratively check for revocation of each certificate **80** using each certificate's indicated CRL. For example, the middlebox **40** is configured iteratively retrieve each CRL for each certificate in the chain. In the case where the middlebox **40** successfully retrieves the CRLs, the middlebox **40** is configured to perform a full-chain CRL check, such as by utilizing LibreSSL.

As a result of validating of the TLS connection and handshaking, the middlebox **40** is configured to generate and forward an offload communication **70** to the service provider device **12**. In response to receiving the offload communication **70** which identifies the secure communication channel **46** between the middlebox **40** and the server device **22**, the service provider device **12** is configured to transmit a communication instruction **72** to the client device **15**. The communication instruction **72** is configured to direct the client device **15** to exchange communication with the server device **22**. For example, the communication instruction **72** can include the IP address of the server device **22** and instructions for the data communication device **16** to exchange network communication with the server device **22** rather than with the selected middlebox **40**. By identifying the presence of a secure communication channel with the server device, the middlebox **40** can remove itself from the communications path while maintaining a level of security with respect to the residential network **14**.

In another arrangement, the middlebox **40** can identify, as an offload condition, a volume of communication exchanged between the data communication device **16** and the server device **22** as meeting a communication volume threshold **74**.

For example, certain services or server devices **22** typically provide streaming content, such as video content (e.g., online streaming motion pictures), to subscribing client devices **15** over secure network or communication channels. For certain types of content, such as motion picture streaming or on-line video games, the presence of the middlebox **40** in the communication channel between the client device **15** and server device **22** can add unacceptable latency to the communication.

In use, the middlebox **40** is configured to detect a volume of communication **82** transmitted between a client device **15** and the server device **22** and can compare the volume to a communication volume threshold **74**. For example, assume the volume of communication **82** is at a rate of 100 packets per second. In the case where the middlebox **40** identifies the volume of communication **82** as meeting the communication volume threshold **74** (e.g., the communication volume threshold **74** is equal to a rate of 100 packets per second), the middlebox **40** is configured to transmit the offload communication **70** to the service provider device **12**.

In response to receiving the offload communication **70** which identifies the volume of communication **82** as meeting the communication volume threshold **74**, the service provider device **12** is configured to transmit a communication instruction **72** to the client device **15**. The communication instruction **72** is configured to establish a communication channel between the client device **15** and the server device **22**, as provided above. By identifying the communication volume between the client device **15** and the server device **22** as meeting a communication volume threshold **72**, the middlebox **40** can remove itself from the communications path to minimize communication latency.

As provided above, the middlebox **40** is configured to transmit the offload communication **70** to the service provider device **12** in response to either identifying a secure communication channel **46** between the middlebox **40** and the server device **22** or identifying a volume of communication exchanged between the data communication device **16** and the server device **22** as meeting a communication volume threshold **74**. In one arrangement, the middlebox **40** is configured to transmit the offload communication **70** to the service provider device **12** in response to identifying both a secure communication channel **46** between the middlebox **40** and the server device **22** and a volume of communication exchanged between the data communication device **16** and the server device **22** as meeting a communication volume threshold **74**.

As provided above, one or more of the client devices **15** of the residential network **14** can be configured as an embedded device, such as a networked light switch. While these embedded devices typically provide a limited number of commands within the residential network **14** (e.g., "turn on," "turn off"), the embedded devices can be subject to user-level network attacks. For example, the embedded devices can be configured to engage in a denial-of-service attach on a server device **20** over the WAN without the knowledge or detection by the residential network operator.

In one arrangement, with reference to FIG. **5**, the service provider device **12** is configured to develop a whitelist or exclusions database **90** that, over time, can identify various client device identifier criteria associated with the embedded devices of the residential network **14**. For example, when an embedded device **18-2** of the residential network **14** transmits a command ("turn on," "turn off") to the data communication device **16**, the data communication device **16** forwards the command as well as information relating to the embedded device **18-2** (e.g., manufacturer, MAC address, etc.) to the service provider device **12** as a client device identifier **92**. In response, the service provider device **12** adds the client device identifier **92** to the whitelist database **90**. As such, the service provider device **12** is configured to learn about the types of embedded device messages it receives over time.

In use, as the service provider device **12** receives device access requests **30** from the data communication device, the service provider device **12** is configured to determine if the source of the device access requests **30** is a compromised embedded device **18-2**. For example, the service provider device **12** can utilize the whitelist database **90** base upon a client device identifier criterion **94** associated with the device access request **30**.

For example, assume the case where the embedded device **18-2** generates a command ("turn on," "turn off") and forwards the command to the data communication device **16**. The data communication device **16** can forward the command to the service provider device **12** as a client device identifier criterion **94** (i.e., as part of a device access requests **30**).

In one arrangement, when the service provider device **12** receives the device access requests **30**, the service provider device **12** is configured to compare the client device identifier criterion **94** with the whitelist database **90**. In response to detecting a lack of correspondence between the client device identifier criterion **94** and an entry in the whitelist database **90**, the service provider device **12** is configured deny any communication between the embedded device **18-2** and the server device **22**. In another arrangement, based upon the client device identifier criterion **94**, the service provider device **12** can identify a manufacturer of the embedded device, such as by using MAC address, to identify specific messages are allowed, or that should be denied, for that device.

In one arrangement, the service provider device **12** is further configured to detect a rate of messages generated by the embedded device within the residential network **14**. For example, assume the case where the service provider device **12** detects that a number of messages (e.g., "turn off") generated by the embedded device over a given time interval meets a threshold. In such a case, the service provider device **12** can perform a rate limiting function, such as by directing the embedded to stop sending the messages. As such, the service provider device **12** limits excessive amount of control traffic within the residential network **14**.

While various embodiments of the innovation have been particularly shown and described, it will be understood by those skilled in the art that various changes in form and details may be made therein without departing from the spirit and scope of the innovation as defined by the appended claims.

What is claimed is:

1. In a service provider device, a method for providing communication between a client device and a server device, comprising:

receiving, by the service provider device, a device access request from the client device via a residential network, the request addressed to an address of the server device, the service provider device being located external to the residential network;

determining, by the service provider device, one of a protocol criterion associated with the device access request and a destination Internet protocol address corresponding to the address of the server device associated with the device access request;

determining, by the service provider device, a communication type identifier associated with the device access request based on a comparison of an entry in a database and one of the protocol criterion and the destination Internet protocol address corresponding to the address of the server device;

selecting, by the service provider device, a middlebox from a plurality of middleboxes, the selecting based on the associated determined communication type identifier;

establishing, by the service provider device, a secure communication channel between the client device and the middlebox associated with the determined communication type identifier; and

providing, by the service provider device, communication between the client device and the server device via the secure communication channel between the client device and the middlebox.

2. The method of claim **1**, wherein determining the communication type identifier associated with the device access request based on the comparison of the entry in the database and the protocol criterion comprises:

comparing, by the service provider device, the protocol criterion with a protocol database; and

determining, by the service provider device, the communication type identifier associated with the device access request based upon a correspondence of the protocol criterion and an entry in the protocol database.

3. The method of claim **1**, wherein determining the communication type identifier associated with the device access request based on the comparison of the entry in the database and the destination Internet protocol address corresponding to the address of the server device comprises:

comparing, by the service provider device, the destination Internet protocol address with a local domain name server database, the local domain name server database including Internet protocol addresses and corresponding domain names; and

determining, by the service provider device, the communication type identifier associated with the device access request based upon a correspondence of the destination Internet protocol address and an entry in the local domain name server database.

4. The method of claim 1, further comprising:

receiving, by the service provider device, an offload communication from the middlebox identifying a secure communication channel between the client device and the server device; and

in response to receiving the offload communication, forwarding, by the service provider device, a communication instruction to the client device, the communication instruction configured to direct the client device to exchange communication with the server device.

5. The method of claim 4, wherein receiving the offload communication from the middlebox identifying a secure communication channel between the client device and the server device comprises receiving, by the service provider device, an offload communication from the middlebox identifying the establishment of a Transport Layer Security (TLS) connection between the client device and the server device.

6. The method of claim 5, further comprising validating, by the service provider device, the TLS connection between the client device and the server device.

7. The method of claim 1, further comprising:

receiving, by the service provider device, an offload communication from the middlebox identifying communication between the client device and the server device as meeting a communication volume threshold; and

in response to receiving the offload communication, forwarding, by the service provider device, a communication instruction to the client device, the communication instruction configured to direct the client device to exchange communication with the server device.

8. The method of claim 1, further comprising:

receiving, by the service provider device, an offload communication from the middlebox identifying a secure communication channel between the client device and the server device and identifying communication between the client device and the server device as meeting a communication volume threshold; and

in response to receiving the offload communication, forwarding, by the service provider device, a communication instruction to the client device, the communication instruction configured to direct the client device to exchange communication with the server device.

9. The method of claim 1, comprising:

detecting, by the service provider device, a client device identifier criterion associated with the device access request;

comparing, by the service provider device, the client device identifier criterion with a whitelist database; and

in response to detecting a lack of correspondence between the client device identifier criterion and an entry in the whitelist database, denying, by the service provider device, communication between the client device and the server device.

10. A service provider device, comprising:

a controller having a memory and a processor, the controller configured to:

receive a device access request from the client device via a residential network, the request addressed to an address of the server device, the service provider device being located external to the residential network;

determine one of a protocol criterion associated with the device access request and a destination Internet protocol address corresponding to the address of the server device associated with the device access request;

determine a communication type identifier associated with the device access request based on a comparison of an entry in a database and one of the protocol criterion and the destination Internet protocol address corresponding to the address of the server device;

select a middlebox from a plurality of middleboxes, the selecting based on the associated determined communication type identifier;

establish a secure communication channel between the client device and the middlebox associated with the determined communication type identifier; and

provide communication between the client device and the server device via the secure communication channel between the client device and the middlebox.

11. The service provider device of claim 10, wherein when determining the communication type identifier associated with the device access request based on the comparison of the entry in the database and the protocol criterion, the controller is configured to:

compare the protocol criterion with a protocol database; and

determine the communication type identifier associated with the device access request based upon a correspondence of the protocol criterion and an entry in the protocol database.

12. The service provider device of claim 10, wherein when determining the communication type identifier associated with the device access request based on the comparison of the entry in the database and the destination Internet protocol address corresponding to the address of the server device, the controller is configured to:

compare the destination Internet protocol address with a local domain name server database, the local domain name server database including Internet protocol addresses and corresponding domain names; and

determine the communication type identifier associated with the device access request based upon a correspondence of the destination Internet protocol address and an entry in the local domain name server database.

13. The service provider device of claim 10, wherein the controller is further configured to:

receive an offload communication from the middlebox identifying a secure communication channel between the client device and the server device; and

in response to receiving the offload communication, forward a communication instruction to the client device, the communication instruction configured direct the client device to exchange communication with the server device.

14. The service provider device of claim 13, wherein, when receiving the offload communication from the middlebox identifying a secure communication channel between the client device and the server device, the controller is configured to receive an offload communication from the

middlebox identifying the establishment of a Transport Layer Security (TLS) connection between the client device and the server device.

15. The service provider device of claim **14**, wherein the controller is further configured to validate the TLS connection between the client device and the server device.

16. The service provider device of claim **10**, wherein the controller is further configured to:

receive an offload communication from the middlebox identifying communication between the client device and the server device as meeting a communication volume threshold; and

in response to receiving the offload communication, forward a communication instruction to the client device, the communication instruction configured to direct the client device to exchange communication with the server device.

17. The service provider device of claim **10**, wherein the controller is further configured to:

receive an offload communication from the middlebox identifying a secure communication channel between

the client device and the server device and identifying communication between the client device and the server device as meeting a communication volume threshold; and

in response to receiving the offload communication, forward a communication instruction to the client device, the communication instruction configured to direct the client device to exchange communication with the server device.

18. The service provider device of claim **10**, wherein the controller is configured to:

detect a client device identifier criterion associated with the device access request;

compare the client device identifier criterion with a whitelist database; and

in response to detecting a lack of correspondence between the client device identifier criterion and an entry in the whitelist database, deny communication between the client device and the server device.

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